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SUMMARY

Pulmonary function tests were performed on 66 Marine Corps volunteer subjects with and without the M17A2 gas mask. Forced vital capacity (FVC) decreased by .2 liter (p=.002) when the mask was worn. Maximum voluntary ventilation decreased by 23.5 l/min (p<.001). The ratio of the volume expired in .5 sec to total FVC was reduced from 58% to 54% (p=.007). Peak flow rates were reduced by 1.6 l/sec (p<.001). These results suggest that the M17A2 gas mask may interfere with strenuous, but not sedentary, activities.

Introduction

Filtering or air purifying respirators are a class of protective devices that include chemical and biologic protective masks, commonly known as gas masks. Such respirators cause increased inspiratory and expiratory resistance, moderately increased dead space (Louhevaara, V.A., 1984), and can cause some psychological stress in the wearer (Morgan, 1983). Subjects are aware of and can fairly accurately assess the magnitude of even small increases in resistance to breathing (Gamberale, F., Holmer, I., Kindblom, A.S., and Nordstrom, A., 1978). Much prior research in this area relates to devices worn in professions such as fire fighting and construction work (Dukes-Dobos, R.J. and Smith, R., 1984; and Louhevaara, V., Smolander, J., Korhonen, O., and Tuomi, T., 1984, 1985, and 1986). Servicemen wearing gas masks in chemical warfare are subject to similar effects.

Previous research has examined the effects of respirators on various respiratory parameters. The different devices studied have provided variable results (Raven, P.B., Dodson, A.T., and Davis, T.O., 1979). There have been several reports of the effects of respirators on pulmonary function tests (Gee, J.B.L., Burton, G., Vassallo, C., and Gregg, J., 1968; McKerrow, 1955; Raven, 1980; Raven, P.B., Moss, R.F., Page, K., Garmon, R., and Skaggs, B., 1981). Pulmonary function tests are the medical standard used to evaluate respiratory function, and provide a uniform way of evaluating the effects of respirators. The M17A2 gas masks are the masks currently in use by most of the United States armed services. The present report describes the effects of this mask on maximum voluntary ventilation (MVV) and forced vital capacity (FVC).

Materials and Methods

Seventy-one volunteer Marines (63 males, 8 females) were studied. Their mean age was 23 years, weight 77 kg, height 175 cm, FVC 5 liters, MVV 159 liters/min, years in service 4, and pay grade E-4. Due to equipment failure data was lost on 5 male subjects. Descriptive statistics by sex are presented in Table 1. These subjects were all healthy, but smokers were not

excluded from the study (38% of subjects were smokers). Each subject underwent FVC and MVV measurements with and without a M17A2 gas mask. Subjects were randomly assigned to perform the mask or the no mask procedures first. The tests were repeated until three satisfactory tests had been accomplished in each condition. Subjects were allowed adequate rest between trials.

Table 1: Population characteristics

MALES (N=58)	MEAN	SD	MIN	MAX
AGE (YEARS)[a]	23.3	3.8	18	34
WEIGHT (KG)	78.4	9.8	54.6	101.6
HEIGHT (CM)	176.5	6.7	162.6	191.1
FVC	5.4	1.0	3.3	7.6
MVV	164.1	26.0	112.6	234.9
YEARS SERVICE	4.7	3.2	0.8	15.0
PAY GRADE[b]	4.1	1.4	2	11
FEMALES (N=8)				
AGE (YEARS)[a]	21.0	3.8	18	29
WEIGHT (KG)	66.6	12.6	52.1	86.3
HEIGHT (CM)	166.7	9.8	154.9	182.9
FVC	4.0	0.4	3.5	4.5
MVV	120.8	14.2	99.9	142.7
YEARS SERVICE[c]	2.3	3.4	0.5	10.0
PAY GRADE[b]	3.0	1.4	2	6

[a] Two males and one female did not supply age information
[b] Pay grade not available on 10 males.
[c] Years in service and pay grade not available on 1 female

SD = standard deviation
MIN = minimum
MAX = maximum
KG = kilograms
CM = centimeters
FVC = best forced vital capacity without mask in liters
MVV = best maximum voluntary ventilation without mask in liters/ min

Measurements were made on a SensorMedics MMC Horizon System 4400 respiratory testing system. This system uses a computer-compensated digital volume transducer to give reliable measures of gas flow. Subjects were tested while seated. For the unmasked condition, air was collected through a standard disposable cardboard mouthpiece (6.3 cm long, 2.3 cm internal diameter) and the nostrils were closed with a nose clip. For the masked

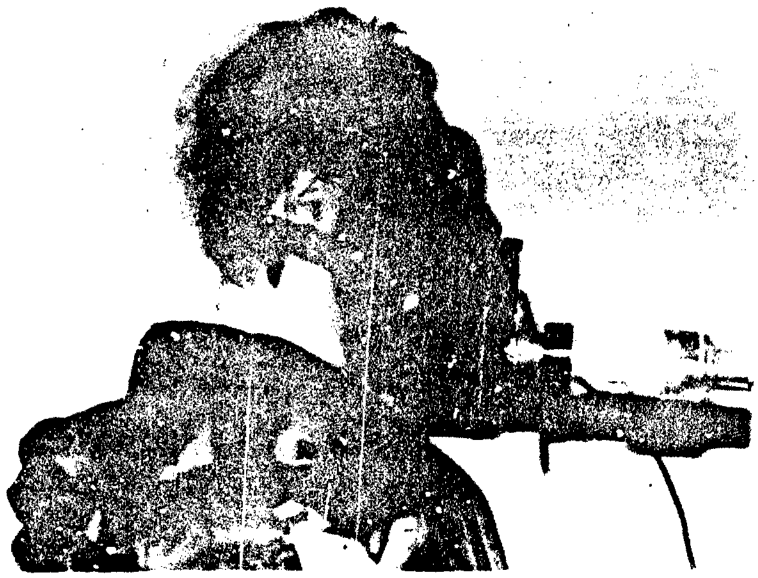

Figure 1: M17A2 Mask with adapter

condition the M17A2 gas mask was modified (Figure 1) to allow exhaled gas to be measured with the transducer. The outlet valve was removed and a brass tube (4.2 cm long, 2.6 cm internal diameter) was attached to the mask outlet. The brass tube fitted over the input side of the volume transducer. A one-way valve (the expiratory valve from the Rudolph 2-Way Mask #7900, with resistance: at 5 l/sec flow = 0.4 cm H20/l/sec; at 13.3 l/sec flow = 0.5 cm H20/l/sec) attached to the other end of the volume transducer prevented the subject from inhaling through the modified frontpiece. Standard combat type inspiratory filters (M13A2) were used in the masks.

Masks were checked for inward leakage by having the subjects forcibly inhale with the input filters covered. In every subject the persistent collapsing of the mask against the face ruled out significant inward leakage. During forced exhalation subjects held the mask against the face to prevent any loss of air around the edges.

The best test in each condition was selected based on maximal FVC or MVV achieved. Statistics were done using the SPSS-X statistical package on a VAX computer. Masked versus unmasked performances were compared using paired t-tests. Males were compared to females and smokers to non-smokers using unpaired t-tests. The level for significance was set to $p \leq .05$.

Results

Baseline Pulmonary Function

All results are summarized in Table 2. Without the mask some parameters from our population's FVC tests were significantly lower than normal values predicted from their age, height, weight, and sex (Morris, J.F., Koski, A., and Johnson, L.C., 1971; Cherniak, R.M. and Raber, M.B., 1972). However, while these differences were statistically significant, few reached a level considered medically meaningful (less than or equal to 80% of predicted for FVC, FEV1, and MVV, less than or equal to 75% of predicted for flow measures (Morris, et. al., 1977). Only average forced expiratory flow at 50% (FEF50) and 75% (FEF75) of forced expiratory volume were less than 75% of predicted. In contrast, MVV was significantly higher than the values predicted by the most commonly used formula (Cherniack and Raber, 1972).

Mask Effects

Almost all measured volumes showed a decrement when the mask was worn. In the FVC test the volume expired in the first .5 second (FEV.5) dropped by 300ml (10%, $p<.001$). No additional decrement occurred during the remainder of the FVC maneuver (i.e. FEV1 and FVC were both down by 200 ml, $p=.001$ and $p=.002$ respectively). FEV.5 included a smaller proportion of the total FVC. No other proportional relationships were changed (e.g. FEV1/FVC was the same with and without the mask). Maximal drops were seen in peak flow and in the high flow portions of the FVC maneuver (FEF 200-1200 and FEF 25%). MVV also showed a large decrement (24 liters, $p<.001$).

Gender Differences

Although our female subjects fit the normal pattern in showing smaller baseline volumes and flows than the males, they generally showed greater

decrements (both absolute and as a percentage of baseline) on FVC measures. This difference was significant only for FEV1, where females dropped by 17% with the mask as compared to 4% in the males (t=-2.73, df=64, p=.008).

Table 2: Pulmonary function measurements without and with mask

	WITHOUT MASK					WITH MASK					t	df	p
	MEAN	SD	%PRE	MIN	MAX	MEAN	SD	%PRE	MIN	MAX			
FVC	5.2	1.0	98	3.3	7.2	5.0	1.0	95	3.1	7.2	3.26	65	.002
FEV.5	3.0	0.5		1.9	3.9	2.7	0.6		0.9	3.9	4.68	65	<.001
FEV1	4.0	0.7	94	2.7	5.6	3.8	0.8	89	1.5	5.3	3.63	65	.001
FEV3[a]	5.1	0.9		3.3	6.9	4.9	0.8		3.2	6.4	4.08	45	<.001
FEV.5/FVC	57.8	8.5		39	77	54.3	11.0		19	74	2.78	65	.007
FEV1/FVC	78.0	8.4		55	92	75.8	10.4		34	93	1.63	65	.108
FEV3/FVC[a]	95.0	4.0		82	100	94.6	3.9		81	100	0.51	45	.614
FEF200-1200	7.5	1.6	91	4.2	11.3	6.2	1.7	76	1.5	9.1	6.37	65	<.001
FEF25	7.1	1.5	86	3.7	10.3	6.3	1.7	77	1.7	9.0	3.91	65	<.001
FEF50	4.3	1.3	70	1.7	6.7	4.0	1.2	66	0.8	7.3	1.78	65	.079
FEF75	1.5	0.6	44	0.3	2.6	1.5	0.6	42	0.5	2.9	0.84	65	.402
FEF25-75	3.4	1.0		1.2	5.4	3.1	1.0		0.8	5.3	2.02	65	.047
FEF75-85	1.0	0.4		0.2	2.2	0.9	0.4		0.2	2.0	1.35	65	.181
PEAK FLOW	8.6	1.6	92	4.7	12.1	7.0	1.7	76	1.9	9.9	8.11	65	<.001
MVV	158.9	28.6	106	99.9	234.9	135.4	22.0	91	82.6	184.0	9.15	65	<.001

[a]Measurement available in both conditions for only 46 subjects
t - two tailed t value
df - degrees of freedom
p - significance, unmasked vs masked
SD - standard deviation
%PRE - percent of predicted normal, available on 63 subjects
MIN - minimum
MAX - maximum
FVC - forced vital capacity, in liters
FEV.5 - volume expired in 1/2 second, in liters
FEV1 - volume expired in 1 second, in liters
FEV3 - volume expired in 3 seconds, in liters
FEV.5/FVC - volume expired in 1/2 second, as a percentage of FVC
FEV1/FVC - volume expired in 1 second, as a percentage of FVC
FEV3/FVC - volume expired in 3 seconds, as a percentage of FVC
FEF200-1200 - average flow rate for the liter of gas expired after the first 200 cc, in liters/second
FEF25 - average flow rate for first 25% of breath volume, in liters/second
FEF50 - average flow rate for first 50% of breath volume, in liters/second
FEF75 - average flow rate for first 75% of breath volume, in liters/second
FEF25-75 - average flow rate during middle half of breath, in liters/second
FEF75-85 - average flow in 10% of breath following middle half, in liters/second
MVV - maximum voluntary ventilation, in liters/minute (based on a 12 second measurement)

Discussion

1. Mask Resistances

Previously reported resistances for the M17A series masks range from 3.4 to 4.3 cm H2O/l/sec inspiratory and 1.05 to 1.4 cm H2O/l/sec expiratory (Johnson, A.T., 1976; Stemler and Craig, 1977; Muza, 1987). The masks in the present study were altered to allow use with the SensorMedics testing system (see Methods section). This modification did not change inspiratory resistance. Expiratory resistance will be that of the one-way valve used (.38 cm H2O/l/sec at 5 l/sec flow) plus that of the expiratory opening itself (minus the standard flutter valve and rubber covering), along with the brass tube. This should not differ greatly from the unaltered mask's expiratory resistance.

The accuracy (in relation to real life) of the usual techniques (using a head form) of measuring mask resistances can be questioned. Johnson, A.T. and Micelli, T.M. (1973) tested a variety of masks, including the M17A1, on a head form as well as on multiple subjects. At high flow rates, some of their subjects had turbulence problems causing increased resistances. The turbulence did not occur with head form testing. Therefore, head form testing could underestimate the resistance that subjects would actually experience.

Love (1980) reviewed various studies and gave recommendations for resistance levels in respirators. He suggested a limit of 6 - 14 cm H2O. Many respirators exceed this limit on inspiratory resistance, expiratory resistance, or both, at high flow rates. The resistance measurements previously reported for the M17A series masks fall below Love's suggested upper limit when flow rates are less than 3.5 l/sec during inspiration or 12 liters/sec during expiration. These flow rates should not be reached with resting breathing. An expiratory flow of 12 l/sec should not be exceeded even during heavy exercise, but inspiratory flows higher than 3.5 l/sec might be. Therefore, this mask might interfere with performance of such exercise.

2. Mask Effects on Pulmonary Function Tests

Table 3 presents a comparison between the changes in pulmonary function testing found in the present study for the M17A2 and those which have been reported for other devices.

Maximum Voluntary Ventilation

McKerrow (1955) studied a series of resistances to determine the effects on MVV. He found that a resistance of 2 cm H2O at 150 l/min flow was sufficient to decrease MVV. Gee, et. al. (1968) found that MVV dropped by 30% with inspiratory and expiratory resistances of 5 cm H20/l/sec at 2 l/sec. The actual time span over which MVV was measured was not specified in these reports. Raven (1980) and Raven, et. al. (1981) studied the effect of the MSA-Ultravue full-face piece respirator mask (inspiratory resistance of 8.5 cm H2O, expiratory resistance of 2.5 cm H20 at 85 l/min flow) on PFTs. MVV (measured for 15 seconds) decreased by 30% in both studies for subjects with normal lung function. Subjects with impaired lung function showed smaller changes.

Subjects in the present study showed a decrease of about 15% in MVV with the mask compared to control. The M17A2 mask has lower inspiratory and expiratory resistances than were reported for Gee's apparatus. Raven et al. (1979) reported even higher resistances. This is consistent with the smaller decrements seen in our subjects. Higher baseline MVV's were associated with larger decreases ($r=.64$, $p<.00001$) in this study. Raven (1980) and Raven et al. (1981) also found greater drops in those with higher baseline MVVs.

Demedts, M. and Anthonisen, N.R. (1973) found that subjects exercising with various added resistances had maximum exercise ventilations of about 70% of their resting MVVs (15 second measurements) for any given resistance. Therefore, the MVV test may be a good measure of how much a mask will interfere with exercise ability. Future studies to evaluate this in relation to the M17A2 mask are planned.

Forced Vital Capacity

Raven (1980) and Raven et al. (1981) included the FVC maneuver in their studies. Raven (1980) found a small change in FVC (3%) with a larger change

Table 3: Decrements seen in pulmonary function tests with m17a2 mask compared with results reported for previously tested devices

	APPARATUS			
	M17A2[a]	MSA ULTRAVUE[b] FULL FACE MASK	MSA ULTRAVUE[c] FULL FACE MASK	GLASS WOOL[d] FILLED TUBE
INSPIRATORY RESISTANCE	2.93cm H20/1/sec at 120 l/min	6.00cm H20/1/sec at 85 l/min	6.00cm H20/1/sec at 85 l/min	5cm H20/1/sec at 120 l/min
EXPIRATORY RESISTANCE	1.10cm H20/1/sec at 120 l/min	1.58cm H20/1/sec at 85 l/min	1.58cm H20/1/sec at 85 l/min	5cm H20/1/sec at 120 l/min
FVC	200 ml (4%)	150 ml (3%)	200 ml (4%)	
FEV1	200 ml (5%)	300 ml (7%)	400 ml (10%)	
FEF50	300 ml/sec (7%)	350 ml/sec (7%)	100 ml/sec (2%)	
FEF75	no change	no change	100 ml/sec (6%)	
MVV_{15sec}	24 l/min (15%)	48 l/min (33%)	39 l/min (29%)	48 l/min (29%)

[a]Resistances stated are for unaltered mask from Muza, 1987.
[b]Raven, 1980. Values from the group of normal subjects.
[c]Raven, et. al., 1981. Values from the group of normal subjects.
[d]Gee, et. al., 1968. Note: paper does not state over what length of MVV was actually measured.

FVC = forced vital capacity
FEV1 = forced expiratory volume in 1 second
FEF50 = forced expiratory flow when 50% of FVC has been exhaled (called Vmax50 in Raven, 1980 and Raven, et. al., 1981)
FEF75 = forced expiratory flow when 75% of FVC has been exhaled (called Vmax25 in Raven, 1980 and Raven, et. al., 1981)
MVV_{15sec} = maximum voluntary ventilation measured over a 15 second period and extrapolated to liters/minute (called MBC_{25} in Raven, 1980; MVV_{25} in Raven, et. al., 1981; and MBC_{UN} and MBC_{OBS} in Gee, et. al., 1968)

in FEV1 (7%). Peak flow dropped by 19%. Raven et al. (1981) found no change in FVC, and FEV1 did not change as a proportion of FVC. Peak flow decreased by 15% (17% in the superior lung function group, 15% in normals, and 12% in impaired).

A similar lack of change in FEV1 as a proportion of FVC and a drop in peak flow of 17% were found in the present study. The ratio of FEV1 to FVC is the measure most often used to detect increased airway resistance (Hinshaw, H.C. and Murray, J.F., 1980) and might be expected to change with the added resistance from the mask. However, the drop in this ratio is

generally associated with lower rather than upper airway obstruction. It has been suggested that the best spirometry indicator of upper airway obstruction is a decreased MVV to FEV1 ratio (Owens, G.R. and Murphy, D.M., 1983). The M17A2 mask did cause a significant decrease in this ratio (unmasked 40.0 vs masked 37.1, t=2.46, df=65, p=.017). The cut off, suggested by Owens and Murphy to discriminate significant upper airway obstruction, was a ratio of less than 25. Our mask values were still well above this ratio.

FVCs and FEV1s dropped by 3% and 6% respectively. FEV3 dropped by 4%. These findings are very close to those of Raven (1980) and Raven et al. (1981). This was unexpected since our adapted version of the M17A2 should have had lower expiratory resistance than the MSA-Ultravue full-face piece respirator mask used in Raven's studies. However, we do not have resistance values for Raven's mask over the full range of relevant flows. Also, turbulence at high flows has been shown to occur sometimes with the M17A1 (Johnson and Micelli, 1973). Perhaps turbulence does not occur with mask Raven studied.

Subjects exercising with a mask tend to take more time for inspiration at the expense of expiratory time (Epstein, Y., Keren, G., Lerman, Y., and Shefer, A., 1982). It has been suggested that ventilation while wearing a mask is limited by a critically short expiratory period (Craig, F.N., Blevins, W.V., and Cummings, E.G., 1970; Johnson, 1976), although there is some disagreement about this (Stemler and Craig, 1977). If expiratory time is the limiting factor, then the amount of air that can be expired in the first .5 to 1 second while wearing a mask may be a good predictor of how the mask will affect exercise performance.

Subjects with higher baseline flow rates showed greater decrement in the high flow portions of the breath (peak flow rate, FEF 200-1200, and FEF 25%). This relationship was apparent whether the amount of change was correlated with the baseline as a percent of predicted or as the simple measurement. Correlations ranged from .40 to .48 (p<.001). Raven et al.

(1981) also found greater decrements in subjects with superior baseline performance.

As noted in the methods section, we had subjects hold the mask against the face during the FVC test to avoid loss of volume out the sides of the mask. In real world situations this would not be the case so we are probably slightly overestimating how much the mask limits expiration. Sufficient pressure to cause such escape of air would only occur during fairly maximal exercise (levels greater than about 60% of maximal oxygen consumption) which is unlikely to occur in the usual circumstances where masks are worn.

Baseline Pulmonary Function

It is interesting that our population showed a consistent pattern of subnormal FEF25-75, FEF50%, and FEF75%, with supranormal MVVs. Our population included smokers while the populations used to generate normal prediction formulas exclude smokers (Morris et al., 1971; Cherniack and Raber, 1972). However, when smokers were excluded from our analysis these measures remained at less than 80% of predicted.

The patterns of change with the mask differed somewhat between smokers and non-smokers. Curiously, smokers tended to show smaller volume decrements than nonsmokers. In fact, while there was still a significant drop in FVC (from 5.3 to 5.1 liter, $T=2.92$, $p=.007$), FEV.5, FEV1, and the volume expired in 3 seconds were not significantly changed by the mask for the smokers. The only flow rates that showed a significant mask effect in smokers were the peak flow rate (decreased from 8.6 to 7.3 l/sec, $t=5.14$, $df=24$, $p<.001$) and the flow in the 200 to 1200 ml range (decrease from 7.6 to 6.5 l/sec, $t=3.71$, $df=24$, $p=.001$). It is unclear why this would be the case. The smokers did not differ significantly from the non-smokers on any of the baseline test measures.

Non-smokers, on the other hand, differed from the overall pattern in showing a drop in the 1 second flow volumes as a proportion of total FVC (from 79% to 75%, $t=2.08$, $df=24$, $p=.043$). This drop disagrees with the

findings of Raven et al., 1981. However, smokers were not separated from non-smokers in their analysis.

There are other studies that have found MVVs greater than the standard normals. Gee et al. (1968) found MVVs a mean of 15.6 liters above predicted in 6 physical education students (calculated from ages and heights given in paper). Mahler, D.A., Moritz, E.D., and Loke, J., (1982) compared marathon runners with sedentary controls. There was no difference between MVVs (or any other parameter measured), but both runners and controls showed supranormal MVVs of about 30 l/min over predicted. (Percent of predicted was not stated. This statement is based on applying the prediction formula to the mean ages and heights presented in the paper). FEF25-75, 50, and 75 are rarely reported in the literature. Raven (1980) and Raven et al. (1981) found that their subjects' measurements of FEF50 and FEF75 were close to predicted values.

One factor which may contribute to disparate results is the variety of equipment used. The present study used a computer-compensated digital system. Raven et al. (1981) used a dry rolling seal spirometer. Gee et al. (1968) used a recording Tissot spirometer, Morris, et. al. (1971) a Stead-Wells spirometer, and Cherniack and Raber (1972) a wedge spirometer. It has been suggested (Sobol, 1976) that a different set of normal values may be needed, not only for every measuring system, but even for every lab (to allow for variation in technique). However, this is not always practical. No universally accepted system appears likely.

Males vs Females

Our small sample size of females does not permit definitive conclusions regarding the greater mask effects seen in females. Our female subjects had less previous experience wearing the mask. The 5 females on whom we have this data all had only 1 hour of previous experience. Previous mask time in males ranged from 0 to 3000 hours. Three subjects who worked as instructors on the use of masks and other protective gear had considerably more experience than anyone else. Data were not available on fourteen subjects. The 43 remaining males had a mean of 26.4 hours of previous experience. Only 24% had 2 or less hours of experience. This may have had more to do with

the male-female differences seen than any underlying physiologic factor. Also, fewer females were smokers (25% vs 40%) and, as noted above, non-smokers tended to show greater mask effects than smokers.

Conclusion

Healthy subjects show significant limitations in volumes and peak flows attainable during FVC and MVV maneuvers when they wear the M17A2 mask. Subjects with the highest baseline flows and volumes show the greatest decrements with the mask. Trends in the data suggest that females may be slightly more impaired by the mask than males. Smokers are less affected than non-smokers. It is expected that baseline MVV, FEV.5, and peak flow during the FVC maneuver will be good predictors of mask exercise limitations. Future studies correlating effects on exercise performance with effects on PFTs are planned to verify this.

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(U) THE EFFECT OF THE M17A2 GAS MASK ON SPIROMETRY VALUES IN HEALTHY SUBJECTS

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The effects of the M17A2 gas mask on respiratory function was evaluated using standard pulmonary function test measurements. Marine volunteers (58 males, 8 females) performed forced vital capacity (FVC) and maximum voluntary ventilation (MVV) manuevers with and without the mask. The subjects were randomly assigned to be tested in the mask or the control condition first. The mask had significant effects on almost all the volumes and flows measured. There was a decrement of 200 ml in the mean FVC (p=.002) and in the forced expiratory volume in 1 second (FEV1, p=.001). The forced expiratory volume in .5 second FEV.5 dropped from 58 to 54% of the total FVC (p=.007), but the other proportional relationships were not changed. Higher baseline flows were correlated with greater drops in flow when the mask was worn (r=.64, p<.001). Mean MVV dropped by 24 liters (15%) (p<.001) in the masked condition. Females dropped their FEV1s by 17%, while males dropped by only 4% (p=.003), with similar nonsignificant trends on other measures. Unlike the overall group, smokers did not show a significant drop in FEV.5, FEV1, the enforced expiratory volume in 3 seconds or the forced expiratory flow rate during the middle half of the breath.

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